MCD Report 2011 - 43

Water Quality Study

Nitrogen and Phosphorus Concentrations and Loads in the Great Miami River Watershed, Ohio 2005 – 2011

Abstract

To evaluate baseline water quality conditions in the Great Miami River Watershed the Miami Conservancy District conducted a six year study of nutrient concentrations, loads, and yields in surface water from 2005–2011. Nutrient monitoring stations were installed at four locations on the rivers to collect data on nitrogen and phosphorus concentrations and loads. The monitoring stations are located near the confluence of the Stillwater River with the Great Miami River; the confluence of the Mad River with the Great Miami River; on the Great Miami River at Dayton, Ohio; and on the Great Miami River at Fairfield, Ohio. These locations are located to record the conditions of the four major subwatersheds of the Great Miami River Watershed: Upper Great Miami River, Lower Great Miami River, Stillwater River, and Mad River. Each monitoring station is located in close proximity to a United States Geological Survey (USGS) streamgaging station which allows nutrient concentration data to be coupled with flow data so as to calculate loads and yields.

The results from this study illustrate that nutrient concentrations in the water column of the Great Miami River and its major tributaries are variable with flow and season. Nitrate was the dominant species of nitrogen detected. The concentrations of total nitrogen and nitrate in samples collected from the Stillwater River and Great Miami River monitoring stations tend to increase with flow. The higher concentrations occur in the winter and spring, and the lower concentrations in the summer and fall which reflects a seasonal influence. The concentrations of nitrate in samples collected from the Mad River tend to remain fairly constant across a wide range of flows and through all of the seasons.

The concentrations of total phosphorus in samples collected at all sampling stations also tend to show variability with flow and season. In general, the concentrations of total phosphorus increase at lower flows and at higher flows, with the lowest concentrations occurring at intermediate flows. The concentrations of total phosphorus are not influenced by the seasons as much as the concentrations of total nitrogen and nitrate. The highest seasonal median concentrations for total phosphorus tend to occur in the summer and fall.

The concentrations of dissolved orthophosphate tend to be highest at low flows in samples collected from the Great Miami River and Mad River. In contrast, the samples collected from the Stillwater River tend to have higher concentrations of dissolved orthophosphate at higher flows. Similar to total phosphorus, median dissolved orthophosphate concentrations are not strongly influenced by the seasons, but do tend to be highest in the fall.

The results of this study show that total nitrogen and total phosphorus yields for the Great Miami River Watershed in 2007, 2008, and 2011 exceeded published mean nutrient yields for the years 1980–1996.

Introduction

This report summarizes a study conducted by Miami Conservancy District (MCD) to track trends in nutrient concentrations and loads in rivers and streams in the Great Miami River Watershed from 2005–2011.

MCD is a watershed-based regional government agency that conducts work throughout the Great Miami River Watershed in southwest Ohio. Conservancy districts are political subdivisions of the State of Ohio. Formed in 1915, MCD provides programs and activities related to water resources including flood protection, water resource monitoring and information, and recreational opportunities.

With headwaters near Indian Lake, the Great Miami River flows 170 miles southwest to its confluence with the Ohio River west of Cincinnati. The Great Miami River Watershed drains all or parts of 15 counties and also includes the Stillwater and Mad Rivers, and Twin, Wolf and Sevenmile creeks. The total drainage area of the Great Miami River Watershed in Ohio is 3,946 square miles; the entire watershed, including the Whitewater River in Indiana, drains 5,371 square miles. For the purposes of this study, the Great Miami River Watershed is defined as the drainage area upstream of the USGS stream gage on the Great Miami River at Hamilton (USGS ID 03274000) which encompasses 3,630 square miles.

For this study, the Great Miami River Watershed is divided into four subwatersheds: Mad River, Stillwater River, Upper Great Miami River, and Lower Great Miami River. The Upper Great Miami River subwatershed encompasses all of the land that drains into the Great Miami River and its tributaries upstream of the USGS streamgaging station at Taylorsville, excluding the Stillwater and Mad River subwatersheds. The Lower Great Miami River subwatershed encompasses all of the land that drains into the Great Miami River and its tributaries downstream of the three USGS streamgaging stations on the Stillwater River at Englewood, on the Great Miami River at Taylorsville, and on the Mad River near Dayton (see Figure 1).

Figure 1.Locations of MCD nutrient monitoring stations and the nearest USGS streamgaging station.

Study Purpose

The Water Conservation Subdistrict of the Miami Conservancy District (MCD) led the development of a market-based program to help reduce nutrient runoff to rivers and streams starting in 2003. Through partnerships with municipal wastewater treatment plant owners and members of the agricultural community the Great Miami River Water Quality Credit Trading Program (Trading Program) was created to incentivize the installation of agricultural best management practices that reduce nutrient runoff to rivers and streams in the Great Miami River Watershed. To track nutrient levels in the rivers and streams of the Great Miami River Watershed, nutrient data collection began in 2005. This report includes the results from all samples that were collected from April 2005 through December 2011.

Nutrients

Nutrients are chemicals that organisms need to live and grow. All living organisms require nutrients to sustain their growth and development. Nitrogen and phosphorus are primary nutrients for algal and macrophyte production and are essential to the functioning of healthy aquatic ecosystems. While nutrients are essential to the functioning of aquatic ecosystems, they can exert negative effects when they are overabundant. Excessive concentrations of nutrients in the water environment alter trophic dynamics by increasing algal and macrophyte production, increasing turbidity (through algal production), decreasing dissolved oxygen (DO) concentrations, and increasing fluctuations in diel DO and pH. These changes shift species composition away from those typical of high quality warmwater streams towards less desirable species compositions of degraded warmwater streams (OEPA, 1999).

Human activities over the last century have increased the total mass of nitrogen and phosphorus introduced each year into aquatic ecosystems. This increase is due to municipal and industrial wastewater discharges, fertilizer use, and atmospheric inputs (Puckett, 1995). Despite the noted improvements in water quality due to improvements in the treatment of wastewater discharges, an overabundance of nutrients in the Great Miami River Watershed still exists (OEPA, 1995); (OEPA, 1997); (OEPA, 2001). Algal blooms on the Great Miami River were observed by the Ohio Environmental Protection Agency (OEPA) in 1995 (OEPA, 1997) and again in 2011 (Smith, 2011). Nutrient enrichment is listed by OEPA as one of the most pervasive causes of impairment in the Upper Great Miami River Watershed in a recent biological and water quality study (OEPA, 2011).

Nutrients in the Great Miami River eventually reach the Gulf of Mexico contributing to hypoxic conditions. A study by Goolsby et al., (1999) on nutrient fluxes into the Gulf of Mexico found that the Great Miami River Watershed had some of the largest nitrogen and phosphorus yields in the entire Mississippi-Atchafalaya River Watershed. More recently, Heidelberg University noted the Great Miami River had the highest concentrations of total and dissolved phosphorus, the highest unit area loads for total and dissolved phosphorus and the third highest unit area load for nitrate nitrogen out of the eight Ohio watersheds monitored by its Ohio Tributary Monitoring Program (Loftus, 2004). Transport of nutrients in spring runoff to the Gulf of Mexico is thought to be responsible for increased algal growth leading to seasonal hypoxic conditions in the Gulf (Rabalais, Turner, and Wiseman, 2002; Scavia, Dubravko, and Bierman, 2004).

Study Design

To assess the nutrient loads in the rivers, water quality samples were collected on a continuous basis at four locations in the Great Miami River Watershed. Data collection was conducted according to a USEPA-approved Quality Assurance Project Plan (QAPP) (MCD, 2009). The monitoring locations were selected so as to track changes in nutrient loads in the four major subwatersheds. These data, along with precipitation and river stage information, provide invaluable insights to nutrient concentrations and loads from and within the Great Miami River Watershed. In addition to providing an indication of the effectiveness of local nutrient management strategies, these data could provide improved quantification of loads that may ultimately impact the Gulf of Mexico (MCD, 2011).

Each monitoring station is located in close proximity to a USGS streamgaging station which allows the nutrient concentration data to be coupled with flow data so as to calculate loads. The first monitoring station is located upstream of the mouth of the Stillwater River at the city of Englewood; the second near the mouth of the Mad River near the city of Dayton; the third on the Great Miami River at the city of Huber Heights; and the fourth on the Great Miami River near the City of Fairfield (see Figure 1 and Table 1).

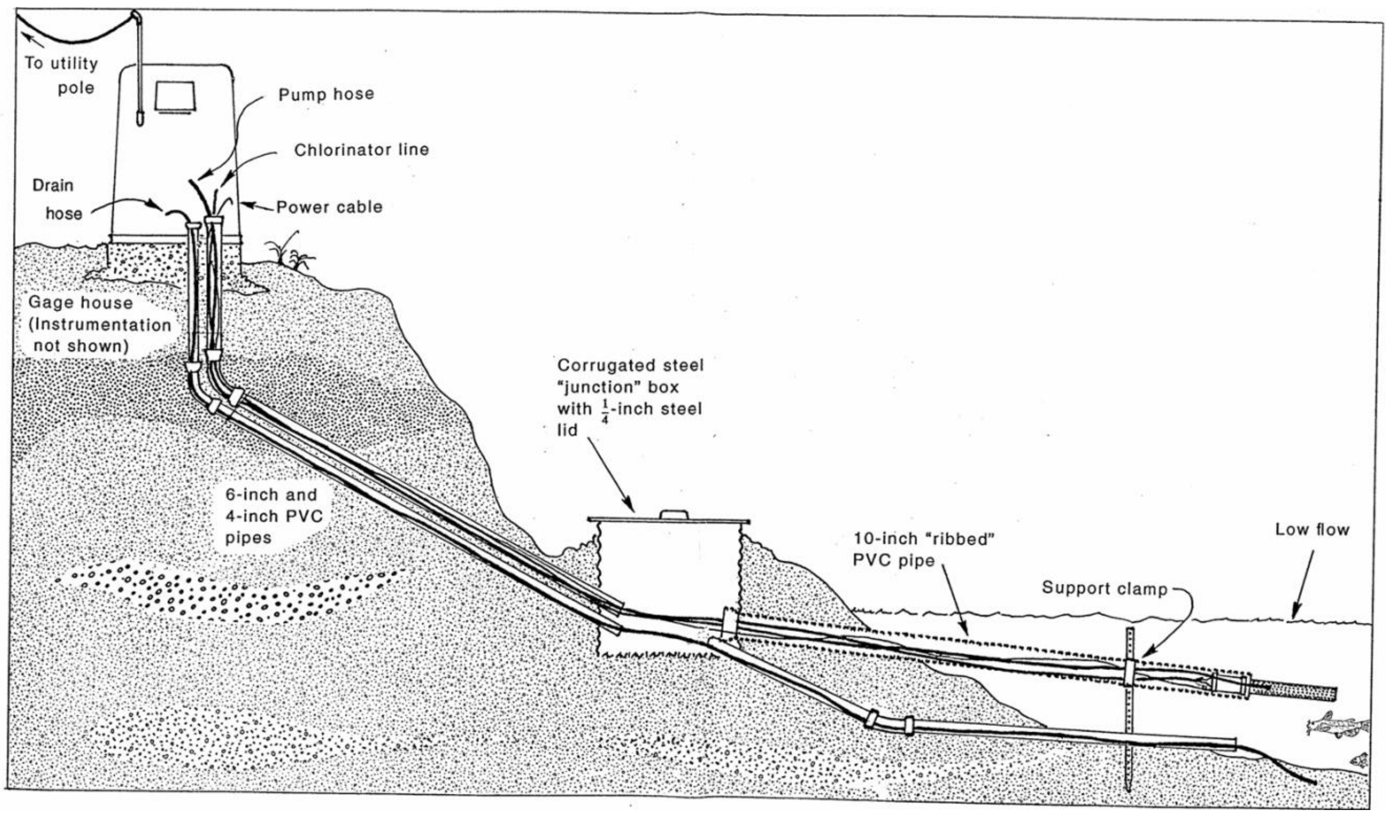
Table 1.Monitoring station names and USGS stream gages.

Reference Number	Monitoring Station Name	Nearest USGS Stream Gage	USGS Gage ID	Drainage Area (mi^2)
1	Stillwater River at Englewood	Stillwater River at Englewood	03266000	650
2	Great Miami River at Huber Heights	Great Miami River at Taylorsville	03263000	1,149
3	Mad River near Dayton	Mad River near Dayton	03270000	635
4	Great Miami River near Fairfield	Great Miami River at Hamilton	03274000	3,630

The sampling station at Englewood collects nutrient load and yield data for the Stillwater River subwatershed upstream of MCD’s Englewood flood protection dam. The sampling station located in Huber Heights collects nutrient load and yield data for the Upper Great Miami River subwatershed. The sampling station on the Mad River is downstream of MCD’s Huffman flood protection dam and collects nutrient load and yield data for the Mad River subwatershed. The sampling station on the Great Miami River near Fairfield is located near the Greater Cincinnati Water Works Bolton Water Treatment Plant and collects nutrient load and yield data for the Great Miami River Watershed upstream of the streamgaging station at Hamilton, Ohio.

An ISCO® refrigerated automatic sampler (autosampler) is used at each monitoring station (see Figure 2). The monitoring stations were constructed in accordance with standard USGS and ISCO® guidance. Surface water is pumped through a three-inch screened intake into a flow-through tank inside the station. Water samples are pumped through the autosampler by a peristaltic pump to the sample containers located inside the refrigerated unit. The autosamplers fill sample containers at eight-hour intervals. YSI 6-series® sondes are deployed in each of the flow-through tanks to collect data on water temperature, specific conductance, pH, turbidity, dissolved oxygen, chlorophyll, and blue-green algae. The sondes are programmed to monitor these water quality parameters at two-hour intervals.

Figure 2.Schematic of a typical nutrient monitoring station in the MCD nutrient monitoring program.



Each monitoring station is visited weekly by MCD staff who collect the filled sample containers, select three sample containers to deliver to a laboratory for nutrient analysis, and resupply the autosamplers with empty containers cleaned by the laboratory.

To decide which sample containers are sent to the laboratory, a weekly review of the occurrence of runoff events is conducted using the streamgaging data on the USGS National Water Information System. The concentrations of nutrients in the river may change rapidly during storm runoff events. The three samples for the week are selected that best capture the rise, peak, and recession phases of the event. Those samples are delivered to the laboratory for analysis of nutrients. If baseflow conditions predominate, the three samples selected are evenly spaced throughout the week. One duplicate sample is also collected each month as a check on reproducibility or consistency in analytical results. The location from which the duplicate sample is collected varies each month. Table 2 summarizes the analytical methods used to measure nutrient concentrations for this study.

Table 2.Summary of parameters and analytical methods used in this study.

Parameter	USEPA Analytical Method	Reporting Limit (mg/L)
Ammonia	350.2	0.05
Nitrite	SM 4500 NO3-F	0.02
Nitrate	SM 4500 NO3-F	0.2
Dissolved Orthophosphate	SM 4500 P-F	0.05
Total Phosphorus	200.7/SW 6010	0.02
Total Kjeldahl Nitrogen	351.2	0.50
Total Suspended Solids	160.2	10

Over 1000 samples were collected at each monitoring station during this study (see Table 3).

Table 3. Period of sample collection and number of samples collected at each monitoring station.

Station	Years Data Collected	Ammonia Samples	Nitrite Sample	Nitrate Samples	TKN Samples	Dissolved Orthophosphate Samples	Total Phosphorus Samples	Total Suspended Solids Samples
Stillwater River at Englewood	2005–2011	1,773	2,050	2,050	2,057	1,944	1,915	2,051
Great Miami River at Huber Heights	2008–2011	1,021	1,018	1,018	1,021	1,001	1,005	1,015
Mad River near Dayton	2007, 2008, 2011	1,682	1,682	1,682	1,678	1,682	1,681	1,632
Great Miami River near Fairfield	2007, 2008, 2011	1,731	1,730	1,730	1,730	1,613	1,731	1,683

Findings – Nutrient Concentrations

Mean Concentrations of Nutrient Species

Mean concentrations were calculated for ammonia, nitrate, nitrite, total Kjeldahl nitrogen (TKN), dissolved inorganic nitrogen (DIN), total nitrogen, dissolved orthophosphate, and total phosphorus from the samples collected (see Figure 3 and Table 4).

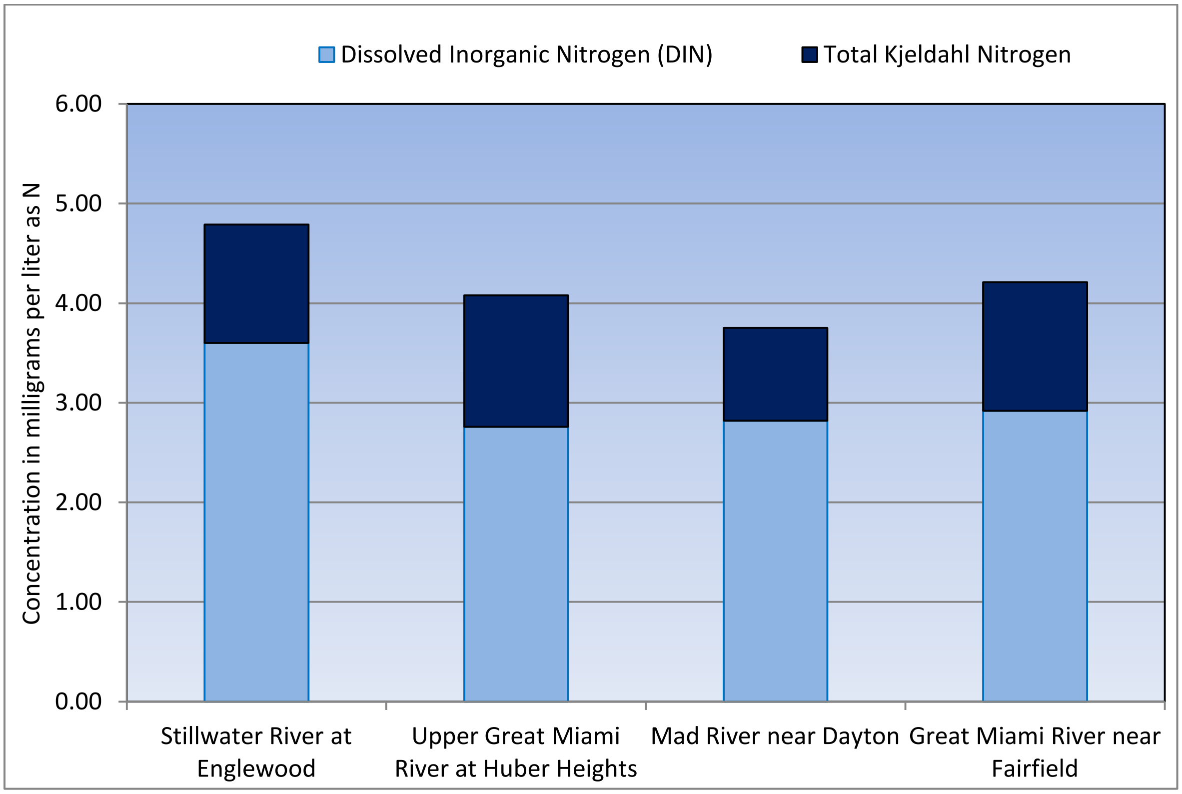
Table 4.Mean concentrations of nutrient species for each nutrient monitoring stations.

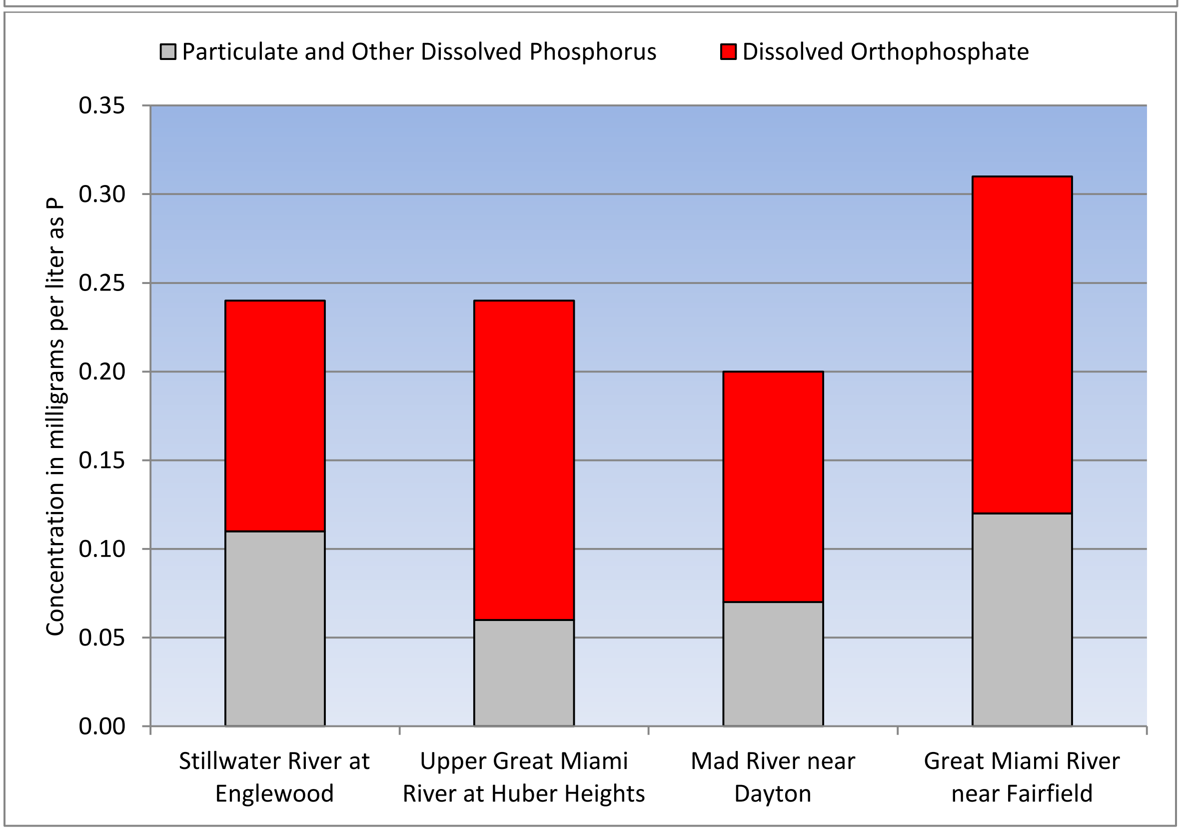
Nutrient Species	Stillwater River at Englewood	Great Miami River at Huber Heights	Mad River near Dayton	Great Miami River near Fairfield
Ammonia (mg/L)	0.14	0.10	0.12	0.07
Nitrite as N (mg/L)	0.17	0.07	0.05	0.06
Nitrate as N (mg/L)	3.29	2.59	2.65	2.79
Total Kjeldahl Nitrogen (TKN) (mg/L)	1.19	1.32	0.93	1.29
Dissolved Inorganic Nitrogen (DIN) (mg/L)	3.60	2.76	2.82	2.92
Total Nitrogen (mg/L)	4.79	4.08	3.75	4.21
Dissolved Orthophosphate (mg/L)	0.13	0.18	0.13	0.19
Total Phosphorus (mg/L)	0.24	0.24	0.20	0.31

Total nitrogen concentrations were calculated by summing the concentrations of all measured nitrogen species in a given sample. The mean concentrations for total nitrogen range between 4.79 mg/L collected at the Stillwater River at Englewood to 3.75 mg/L collected at the Mad River near Dayton. Nitrate is the dominant form of nitrogen at all four monitoring stations comprising an average of 67 percent of the mean total nitrogen concentration. Mean nitrate concentrations range from 3.29 mg/L collected at the Stillwater River at Englewood to 2.59 mg/L collected at the Great Miami River at Huber Heights.

Total Kjeldahl Nitrogen (TKN) is also a significant component of total nitrogen comprising an average of 28 percent of the mean total nitrogen concentration. Mean TKN concentrations range from 1.32 mg/L collected at the Great Miami River at Huber Heights to 0.93 mg/L collected at the Mad River near Dayton. Ammonia and nitrite are relatively minor constituents in comparison each comprising less than 5 percent of the mean total nitrogen concentration.

Figure 3.Mean concentration distribution of nitrogen and phosphorus species calculated from samples collected at each of the four nutrient monitoring stations.





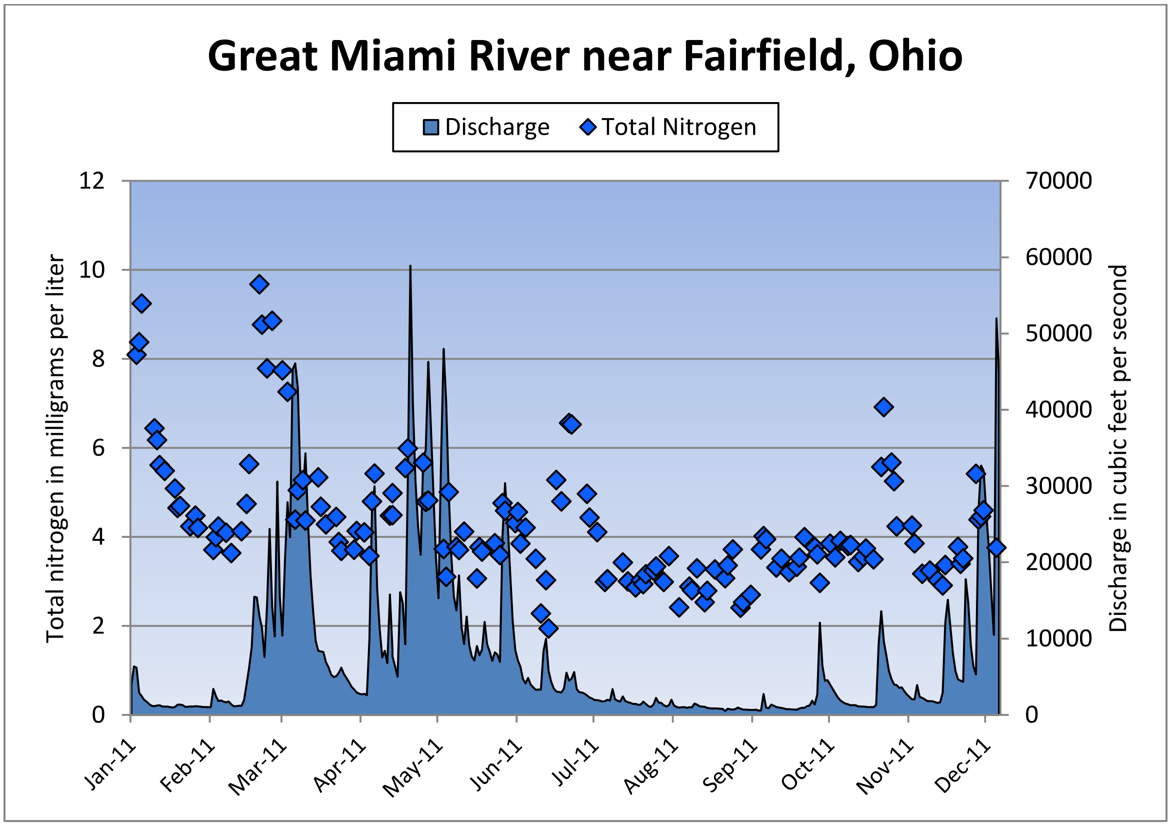
For the purpose of this study, dissolved inorganic nitrogen (DIN) is defined as the sum of ammonia, nitrate, and nitrite concentrations. These inorganic forms of nitrogen are the most reactive nitrogen species in aquatic ecosystems. Mean DIN concentrations range from 3.60 mg/L collected at the Stillwater River at Englewood to 2.76 mg/L collected at the Great Miami River at Huber Heights. Nitrate is the most dominant species of DIN comprising an average of 94 percent of the mean DIN concentration at each station.

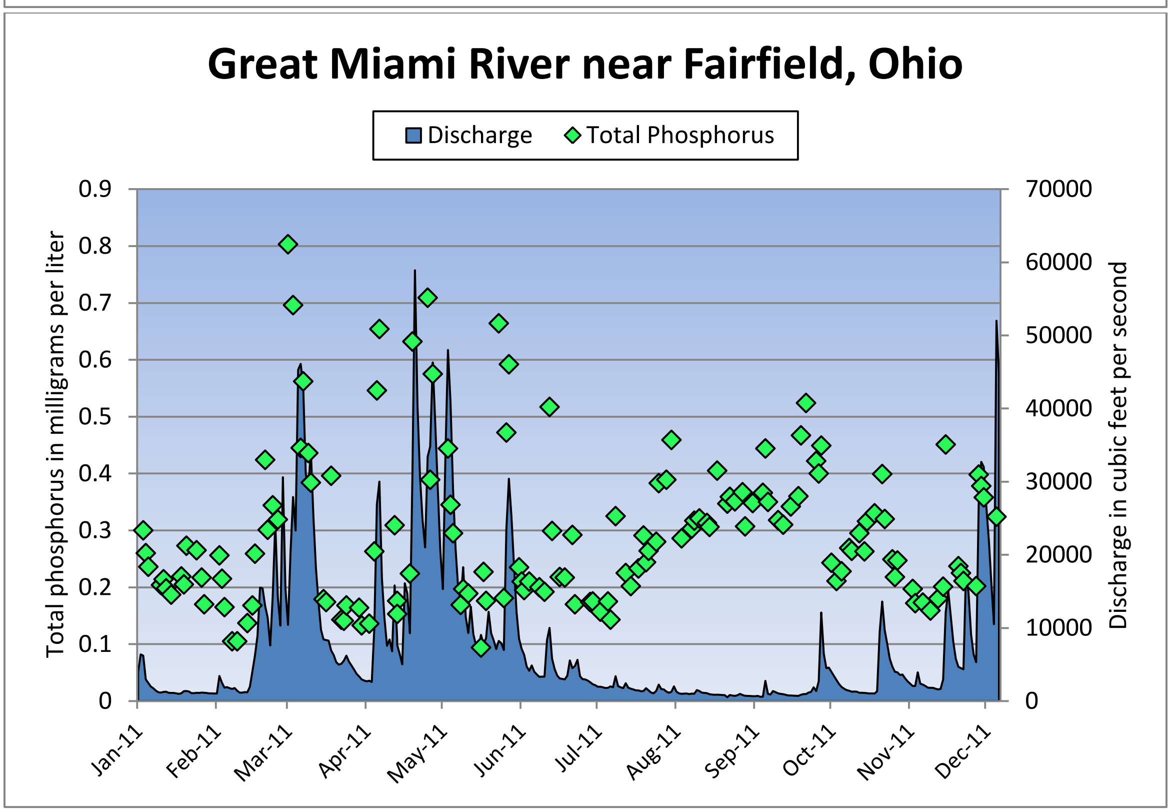
The mean concentrations for total phosphorus range between 0.31 mg/L collected at the Great Miami River near Fairfield to 0.20 mg/L collected at the Mad River near Dayton. Dissolved orthophosphate is the dominant form of phosphorus at all four stations comprising an average of 63 percent of the mean total phosphorus concentration. Mean dissolved orthophosphate concentrations range from 0.13 mg/L collected at the Stillwater River at Englewood and at the Mad River near Dayton to 0.19 mg/L collected at the Great Miami River near Fairfield.

Variations in Nutrient Concentrations with Flow

Concentrations of nutrients in the surface waters of the Great Miami River Watershed change rapidly with in stream flows (see Figure 4). In general, total nitrogen and total phosphorus concentrations tend to increase during runoff events. However, elevated total phosphorus concentrations also occur during low flows whereas elevated total nitrogen concentrations are usually associated with runoff events and remain low during low flows.

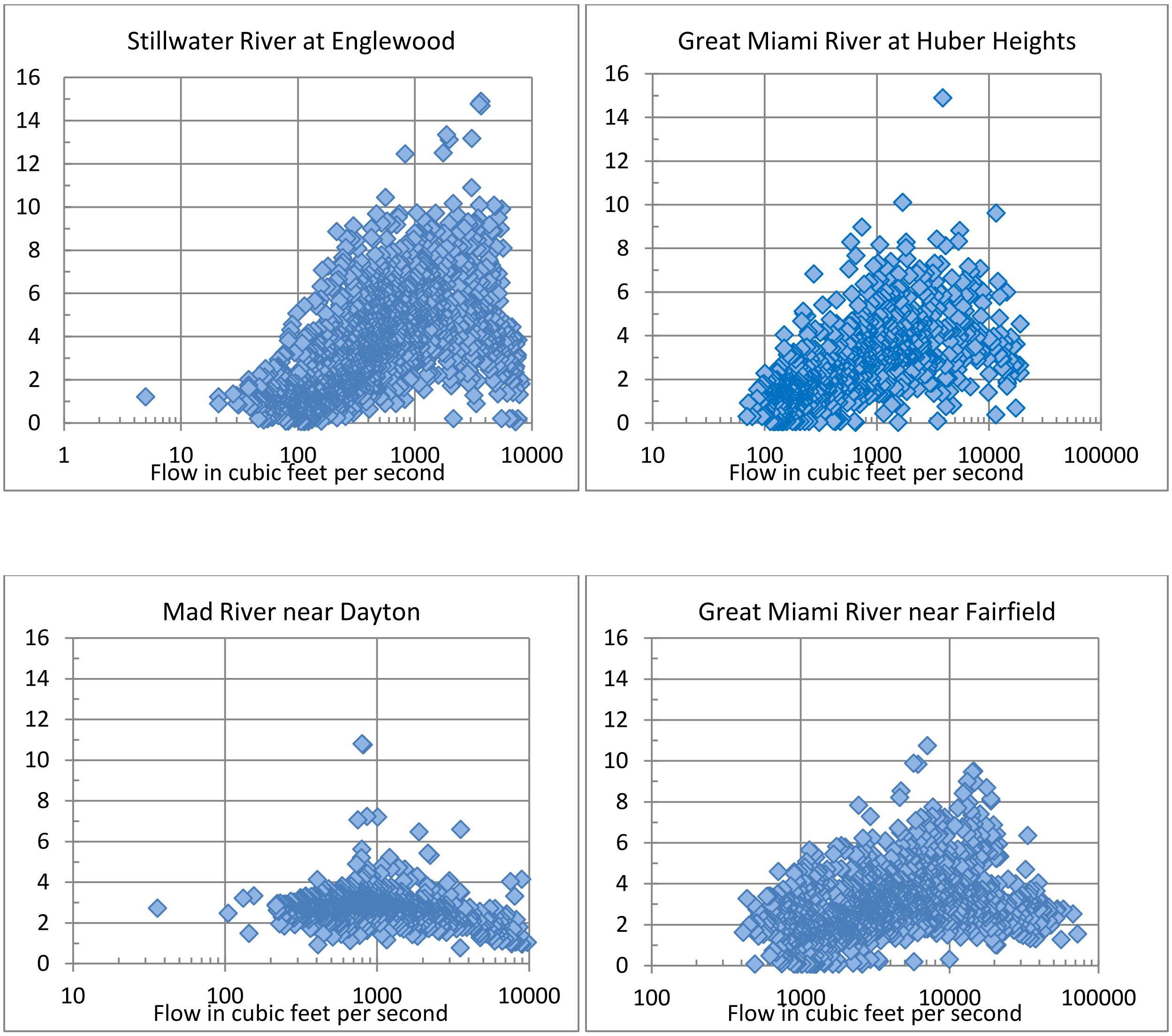
Figure 4 The variability of total nitrogen and total phosphorus concentrations with stream flow during 2011.





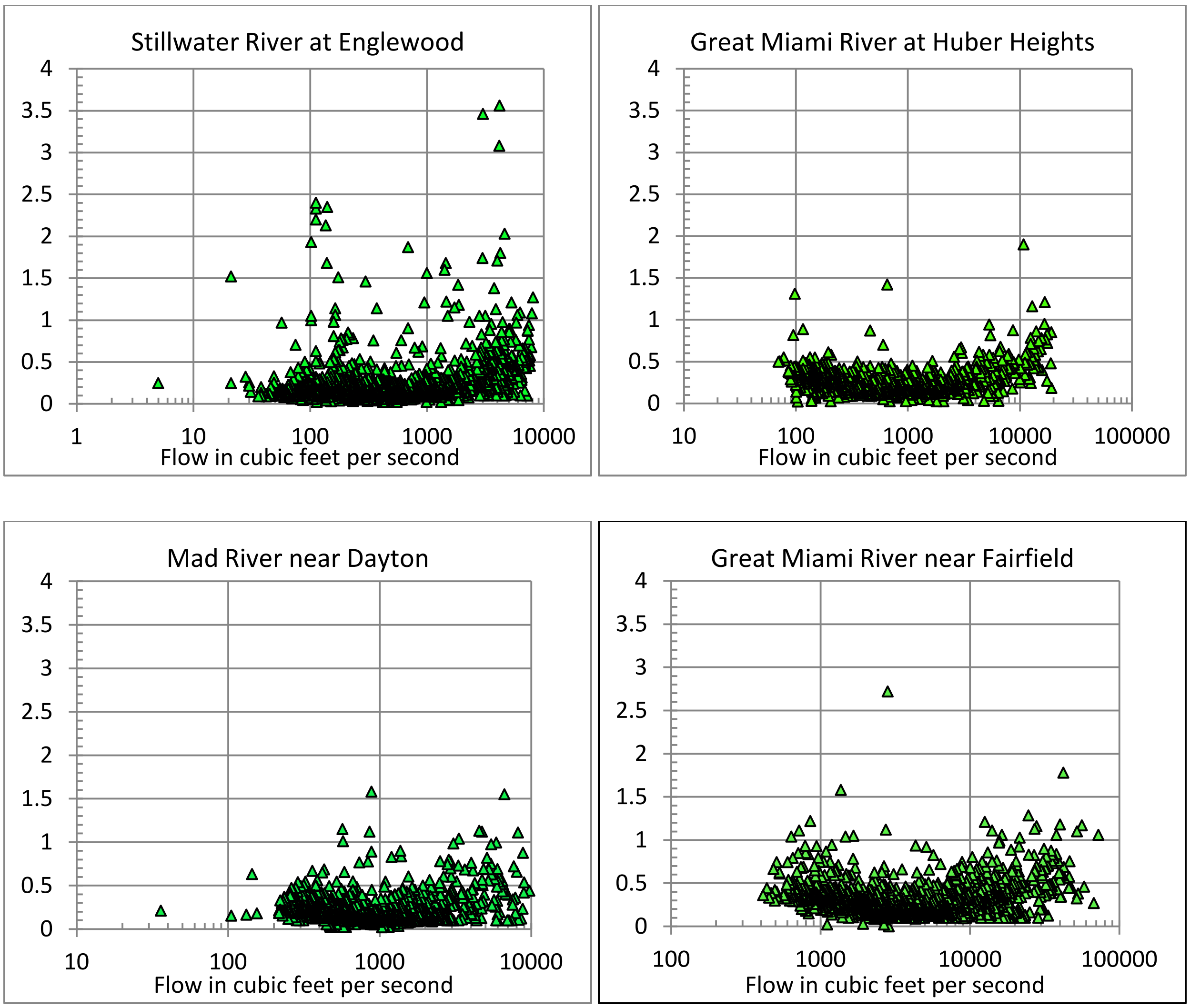
Graphical plots of DIN versus flow at the Stillwater River at Englewood, Great Miami River at Huber Heights, and the Great Miami River near Fairfield stations illustrate a strong tendency for DIN concentrations to increase with increasing flow (see Figure 5). DIN concentrations for the Mad River near Dayton station behave differently and do not show the same tendency to increase with increasing flows as the other stations. DIN concentrations for the Mad River near Dayton station at low flow tend to be higher than low flow DIN concentrations at the other stations.

Figure 5.Concentrations of dissolved inorganic nitrogen (DIN) in milligrams per liter versus stream flow.



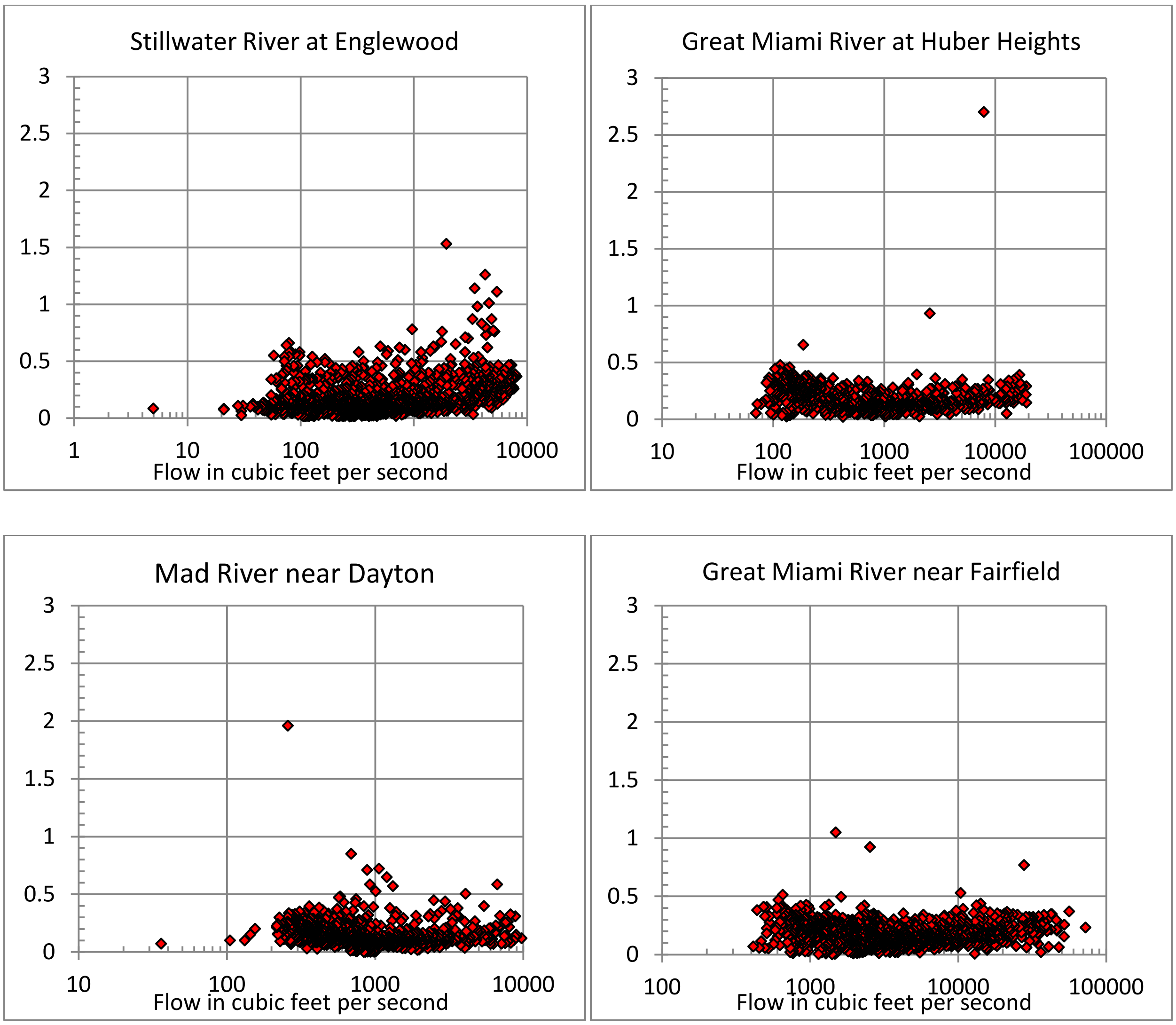
Graphical plots of total phosphorus versus flow for all nutrient monitoring stations have a concave or U-shape because concentrations of total phosphorus illustrate a tendency to increase at the low flow and high flow ends of the graph (see Figure 6). In this study, the lowest total phosphorus concentrations tend to occur in samples collected during intermediate flow conditions.

Figure 6.Concentration of total phosphorus (TP) in milligrams per liter and stream flow.



Graphical plots of dissolved orthophosphate versus flow for all nutrient monitoring stations illustrate a tendency for dissolved orthophosphate to remain relatively constant for high and intermediate flows but to increase slightly at low flow conditions (see Figure 7). The plot for the Stillwater River at Englewood station differs from the other station plots because it illustrates a tendency for dissolved orthophosphate to increase at higher flows.

Figure 7.Concentration of dissolved orthophosphate in milligrams per liter and stream flow.



Mean concentrations of nutrient species were calculated for samples collected under different flow conditions at each of the stations (see Table 5). For the purposes of this study, low flows are defined as flows that are less than, or equal, to the 90th percentile discharge in cubic feet per second. High flows are defined as flows that are greater than, or equal, to the upper 10th percentile discharge in cubic feet per second.

Table 5.Mean nutrient concentrations of samples collected under different flow conditions.

Station	Flow Conditions	Discharge (cfs)	Ammonia (mg/L)	Nitrite (mg/L	Nitrate (mg/L)	TKN (mg/L)	DIN (mg/L)	Total Phosphorus (mg/L)	Dissolved Orthophosphate (mg/L)
Stillwater River at Englewood	Low	< 45	0.15	0.08	0.94	1.13	1.17	0.25	0.09
	High	> 1,500	0.16	0.09	5.03	2.09	5.28	0.44	0.28
	All Samples	5 –8,090	0.14	0.17	3.29	1.19	3.60	0.24	0.13
Great Miami River at Huber Heights	Low	< 99	0.11	0.10	1.35	1.03	1.56	0.45	0.21
	High	> 2,540	0.10	0.11	3.95	1.59	4.16	0.42	0.20
	All Samples	70–19,148	0.10	0.07	2.59	1.32	2.76	0.24	0.18
Mad River near Dayton	Low	< 263	0.13	0.07	2.45	0.83	2.65	0.27	0.24
	High	> 1,360	0.12	0.07	2.30	1.37	2.49	0.29	0.13
	All Samples	36–9,750	0.12	0.05	2.65	0.93	2.82	0.20	0.13
Great Miami River near Fairfield	Low	< 521	0.12	0.05	1.89	1.89	2.06	0.44	0.22
	High	> 8,020	0.12	0.09	3.39	1.81	3.60	0.42	0.20
	All Samples	413–72,600	0.07	0.06	2.85	1.46	2.98	0.31	0.18

The data in Table 7 illustrates that mean high flow concentrations of nitrate for the Stillwater River at Englewood, the Great Miami River at Huber Heights and the Great Miami River near Fairfield stations are significantly higher than the low flow and the all sample mean concentrations of nitrate. Mean nitrate concentrations for the Mad River near Dayton station are fairly uniform across all flows. The low flow mean nitrate concentration for this station was significantly higher than the other stations while the high flow mean nitrate concentration was significantly lower.

Mean DIN concentrations at the MCD sampling stations illustrate similar relationships with flow as nitrate. Mean DIN concentrations at high flows are significantly higher than low flow and all sample mean concentrations for the Stillwater River at Englewood, the Great Miami River at Huber Heights, and the Great Miami River near Fairfield stations. Nitrate is the largest component of DIN, so this similarity is not surprising. Mean high flow nitrate and DIN concentrations for the Stillwater River at Englewood station were the highest of the four nutrient sampling stations.

Mean TKN concentrations for high flows are greater than low flow and all sample mean concentrations for the Stillwater River at Englewood, Great Miami River at Huber Heights, and the Mad River near Dayton stations indicating that runoff events tend to elevate TKN concentrations at those stations. The mean TKN concentration for the Great Miami River near Fairfield station did not show this tendency and was highest for low flow conditions.

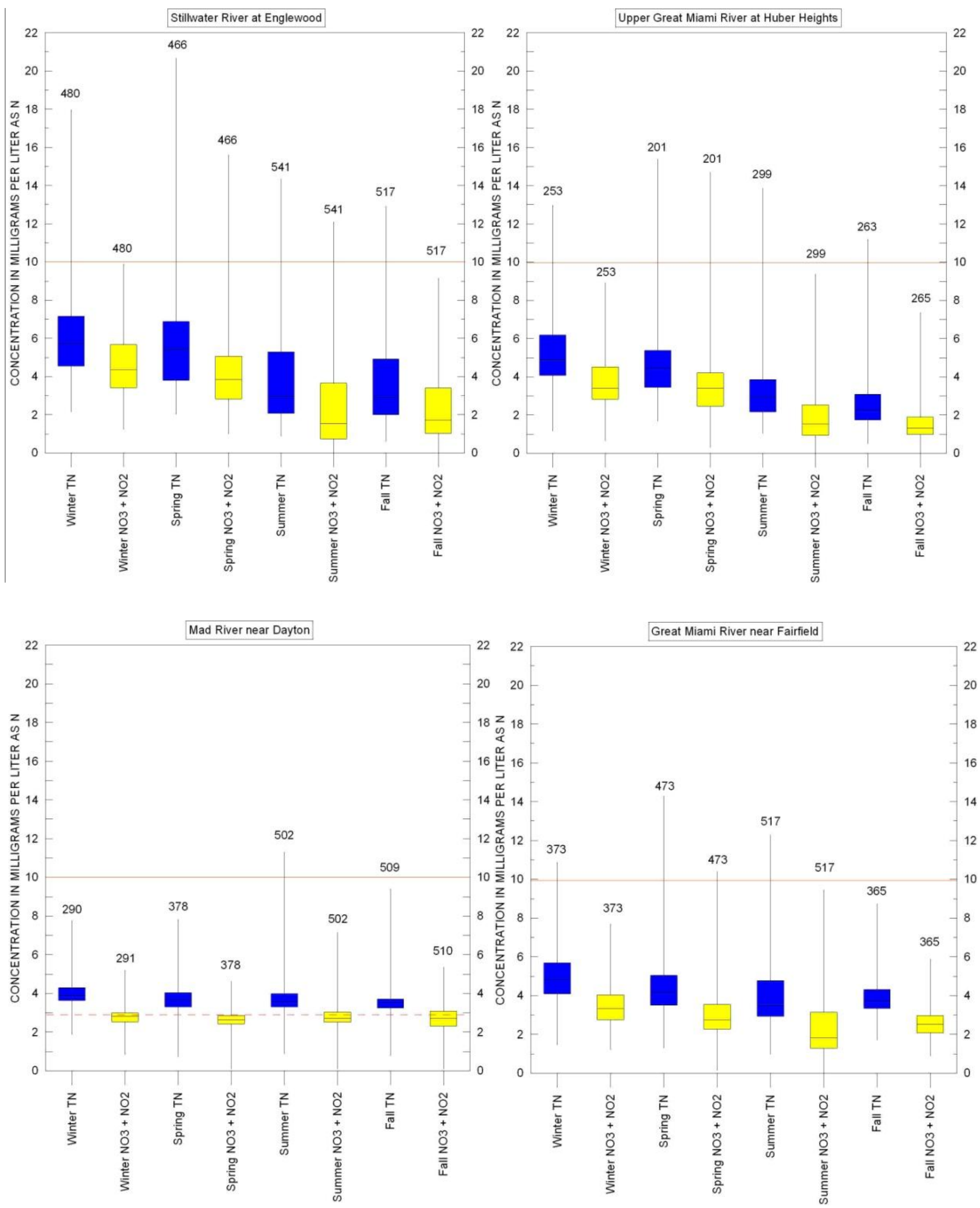
Table 5 illustrates that mean total phosphorus concentrations at low and high flows tend to be greater than the all sample mean at all sampling stations. High flow mean total phosphorus concentrations are greater than low flow concentrations for the Stillwater River at Englewood and Mad River near Dayton stations. Low flow mean concentrations of total phosphorus are greater than high flow mean concentrations for the Great Miami River at Huber Heights and the Great Miami River near Fairfield stations.

Mean dissolved orthophosphate concentrations at low flow conditions are greater than the high flow and all sample means for the Great Miami River at Huber Heights, Mad River near Dayton, and Great Miami River near Fairfield stations. The mean dissolved orthophosphate concentration for the Stillwater River at Englewood was greatest for high flow conditions. The monitoring station on the Stillwater River at Englewood had a significantly lower mean low flow concentration of dissolved orthophosphate in comparison to the other monitoring stations.

Variations in Nutrient Concentrations with Season

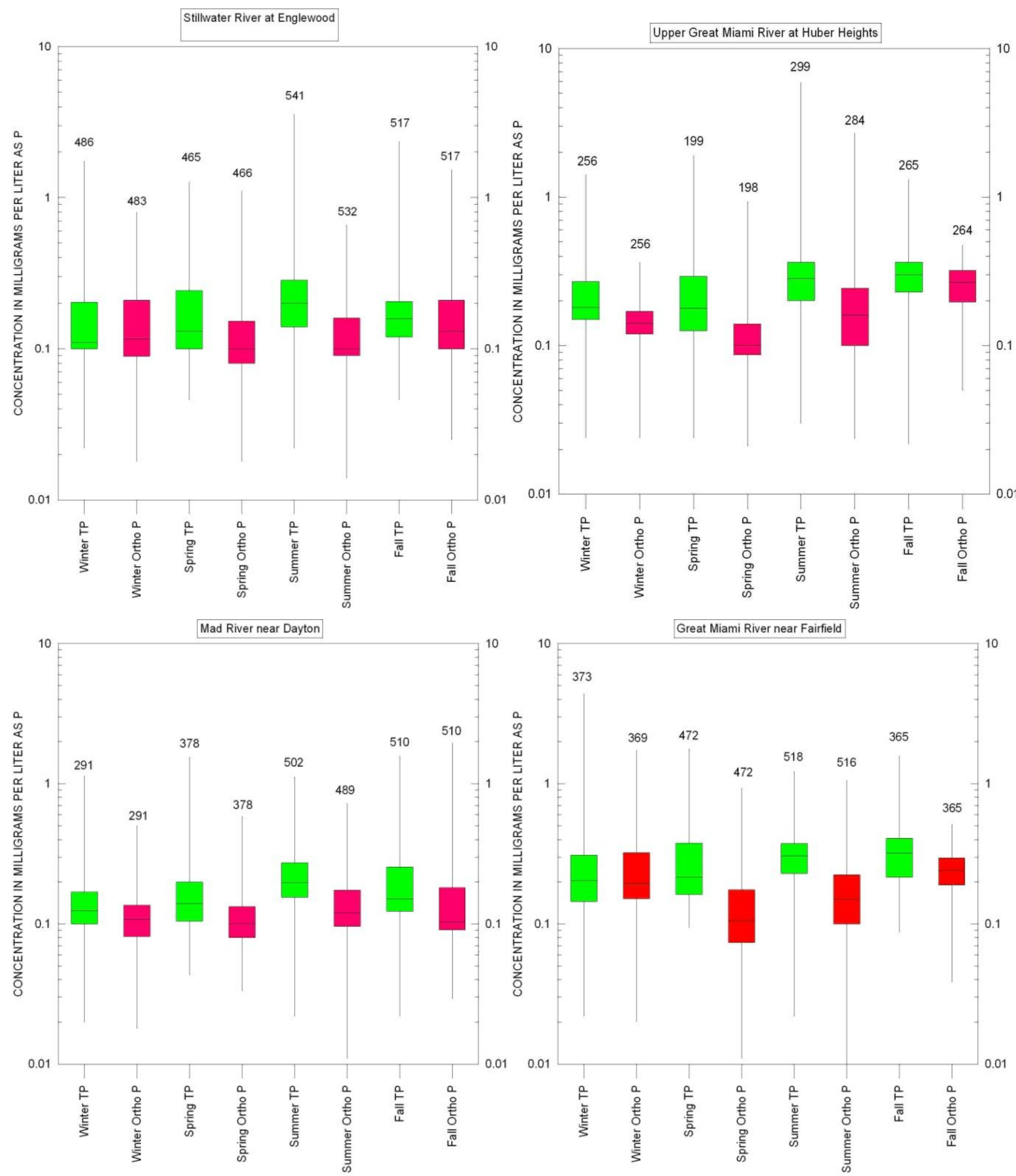
The concentrations of nitrogen and phosphorus recorded in this study vary with season as well as flow. The total nitrogen and nitrate nitrogen concentrations measured at the Stillwater River at Englewood, Great Miami River at Huber Heights, and the Great Miami River near Fairfield show seasonal variations. The highest median concentrations were recorded in the winter and spring and lower median concentrations in the summer and fall (see Figure 8). This seasonal variation in nitrogen concentrations was not as pronounced for samples collected at the Mad River near Dayton station. In fact, the results of this study illustrate very little variation in seasonal median total nitrogen and nitrate nitrogen concentrations measured in samples collected at the Mad River near Dayton station.

Figure 8. Seasonal variations in total nitrogen and nitrate plus nitrite nitrogen concentrations. Boxes enclose the 25th and 75th percentiles, vertical lines show the range, the solid red line is drinking water MCL for nitrate plus nitrite.



Seasonal variations in total phosphorus and dissolved orthophosphate concentrations are different than those of nitrogen and not as pronounced. Median concentrations of total phosphorus and dissolved orthophosphate tend to be highest during the summer and/or fall at all sampling stations (see Figure 9).

Figure 9.Seasonal variations in total phosphorus and dissolved orthophosphate concentrations. Boxes enclose the 25th and 75th percentiles, vertical lines show the range.



Discussion of Nutrient Concentrations

The analysis of nitrogen species from water samples collected at the Stillwater River at Englewood, Great Miami River at Huber Heights, and the Great Miami River near Fairfield monitoring stations show strong variations in concentration with flow and season. In general, concentrations of nitrate nitrogen and TKN, which is the most abundant species of nitrogen, tend to increase with flow and are strongly associated with runoff events. DIN, which consists mostly of nitrate nitrogen, reflects similar behavior. There are also pronounced seasonal variations in total nitrogen and nitrate nitrogen concentrations with the highest median concentrations occurring in the winter and spring seasons. These tendencies suggest that nitrate nitrogen and TKN concentrations are runoff driven and nonpoint sources of nitrogen are the primary driver of the abundance of these nitrogen species in the water column.

The relationships between in-stream flows, season, and nitrogen species concentrations are different at the Mad River near Dayton station when compared with the other stations. Mean TKN concentrations recorded at the Mad River near Dayton station are highest at high flows similar to the other monitoring stations. However, nitrate nitrogen and DIN do not show a tendency to increase with flow, and seasonal variations in total nitrogen and nitrate plus nitrite are minor in comparison with the other stations. Furthermore, mean low flow nitrate concentrations recorded at the Mad River near Dayton are the highest of all the four stations used in this study.

In comparison, Rowe et al., (2004), reported a significant correlation between average nitrate concentration in surface water during periods of low flow and the amount of base flow for streams in the Great Miami River Watershed. The Rowe study reported that the Mad River had the highest median nitrate concentration at low flow and the highest unit area base flow out of all the major rivers and streams they sampled in the Great Miami River Watershed between 1999 and 2001. Their study reported a median nitrate plus nitrite concentration at low flow of 3.5 mg/L for a monitoring station on the Mad River at Eagle City. A median nitrate concentration of 3.3 mg/L was also found in samples collected from shallow groundwater wells in the Mad River subwatershed. The similarities in median nitrate plus nitrite concentrations between surface water and groundwater suggest that the nitrate flux into the Mad River from groundwater may be the most significant source of nitrogen in the water column for the Mad River subwatershed. Studies by Jones et al., (1996) and MCD (2004) also support this conclusion. In comparison, this study found a mean low flow concentration of nitrate plus nitrite for the Mad River near Dayton of 2.52 mg/L. This value is lower than the median nitrate plus nitrite value reported by Rowe, but is the highest value found at the four monitoring stations in this study.

The concentrations of phosphorus in the water column also vary with flow and season. High flows are associated with elevated total phosphorus at all of the monitoring stations. However, dissolved orthophosphate concentrations did not increase significantly with flow for the Great Miami River at Huber Heights, the Mad River near Dayton, and the Great Miami River near Fairfield monitoring stations.

Low flows are associated with total phosphorus and dissolved orthophosphate concentrations at all monitoring stations. Seasonal variations in phosphorus concentrations differ from nitrogen concentrations resulting in the highest median concentrations of total phosphorus and dissolved orthophosphate occurring in the summer and fall seasons. Processes that introduce dissolved orthophosphate under low flow conditions seem to play an important role in determining phosphorus concentrations in the water column at all sampling stations during periods of low stream flow.

Findings - Annual Nutrient Loads

The annual load for a pollutant in a river or stream is defined as the total mass of that pollutant transported by the river or stream in a given year. Calculation of a pollutant load requires information on the stream flow, pollutant concentration, and time for which the stream flow and pollutant concentration data is to be applied. A numeric integration approach is used to calculate pollutant loads (Richards, 1998). The equation used is:

$$\text{Load} = k\sum_{i=1}^{n} c_i q_i t_i$$

Where k is a constant used to convert units to metric tons/year, c_i is the ith observation of concentration, q_i is the corresponding observation of flow, and t_i is the time interval represented by the ith sample.

Total nitrogen and total phosphorus annual loads calculated for each sampling station for the years 2006–2011 are illustrated in Table 6. Because data collection began in April 2005, there was insufficient data to estimate loads at any of the monitoring stations for calendar year 2005. The table also illustrates annual river discharge measured at or near each sampling station. Loads for the Lower Great Miami River subwatershed are estimated by subtracting the loads calculated at the Stillwater River at Englewood, Great Miami River at Huber Heights, and Mad River near Dayton stations from the load calculated at the Great Miami River near Fairfield station.

Table 6.Calculated loads for nitrogen and phosphorus.

Constituent	Stillwater River at Englewood (Stillwater River Subwatershed)					
	2006	2007	2008	2009	2010	2011
Total Discharge (acre-feet)	614,696	663,828	754,258	377,304	474,368	862,054
Total Nitrogen (metric tons)	5,550	4,463	6,148	3,417	4,642	6,056
Total Phosphorus (metric tons)	165	365	519	118	175	322
Constituent	**Great Miami River at Huber Heights (Upper Great Miami River Subwatershed)**					
	2006	2007	2008	2009	2010	2011
Total Discharge (acre-feet)	N/A	N/A	1,478,988	528,798	669,138	1,773,883
Total Nitrogen (metric tons)	N/A	N/A	9,600	3,914	4,434	8,994
Total Phosphorus (metric tons)	N/A	N/A	688	174	314	785
Constituent	**Mad River near Dayton (Mad River Subwatershed)**					
	2006	2007	2008	2009	2010	2011
Total Discharge (acre-feet)	N/A	697,275	742,710	N/A	N/A	981,612
Total Nitrogen (metric tons)	N/A	3,242	3,493	N/A	N/A	4,133
Total Phosphorus (metric tons)	N/A	206	239	N/A	N/A	291
Constituent	**Lower Great Miami River Subwatershed**					
	2006	2007	2008	2009	2010	2011
Total Discharge (acre-feet)	N/A	N/A	1,164,511	N/A	N/A	2,291,745
Total Nitrogen (metric tons)	N/A	N/A	7,630	N/A	N/A	9,794
Total Phosphorus (metric tons)	N/A	N/A	1,007	N/A	N/A	1,448
Constituent	**Great Miami River near Fairfield (Great Miami River Watershed)**					
	2006	2007	2008	2009	2010	2011
Total Discharge (acre-feet)	N/A	3,471,558	4,141,823	N/A	N/A	5,911,167
Total Nitrogen (metric tons)	N/A	18,619	26,879	N/A	N/A	28,991
Total Phosphorus (metric tons)	N/A	1,513	2,455	N/A	N/A	2,848

The Stillwater River at Englewood station was the only station active for the entire period of 2006–2011. The load data for this station illustrates that the highest total nitrogen and total phosphorus loads occurred in 2008 with a total nitrogen load of 6,148 metric tons and a total phosphorus load of 519 metric tons. The highest annual river discharge occurred in 2011 when the station at Englewood recorded over 862,000 acre-feet of water. The lowest total nitrogen and phosphorus loads for this station were recorded in 2006 when the annual river discharge was slightly more than 377,000 acre-feet of water.

The highest total nitrogen load was recorded at the Great Miami River near Huber Heights station in 2008 at 3,493 metric tons. The highest total phosphorus load occurred in 2011 at 785 metric tons and the highest annual discharge in that same year at 1,773,883 acre-feet. The lowest total nitrogen and phosphorus loads were recorded in 2009 when the annual river discharge was almost 529,000 acre-feet of water.

There is sufficient data to calculate annual loads for the Mad River near Dayton station for three separate years; 2007, 2008, and 2011. The calculations show that the highest annual load for total nitrogen and phosphorus were recorded in 2011. The lowest total nitrogen and phosphorus loads were recorded in 2007.

Sufficient data is also available to calculate annual loads for the Great Miami River near Fairfield station for calendar years 2007, 2008, and 2011. The annual load calculations illustrate the highest annual loads for total nitrogen and phosphorus, as well as annual river discharge, was recorded in 2011. The lowest total nitrogen and phosphorus loads were recorded in 2007.

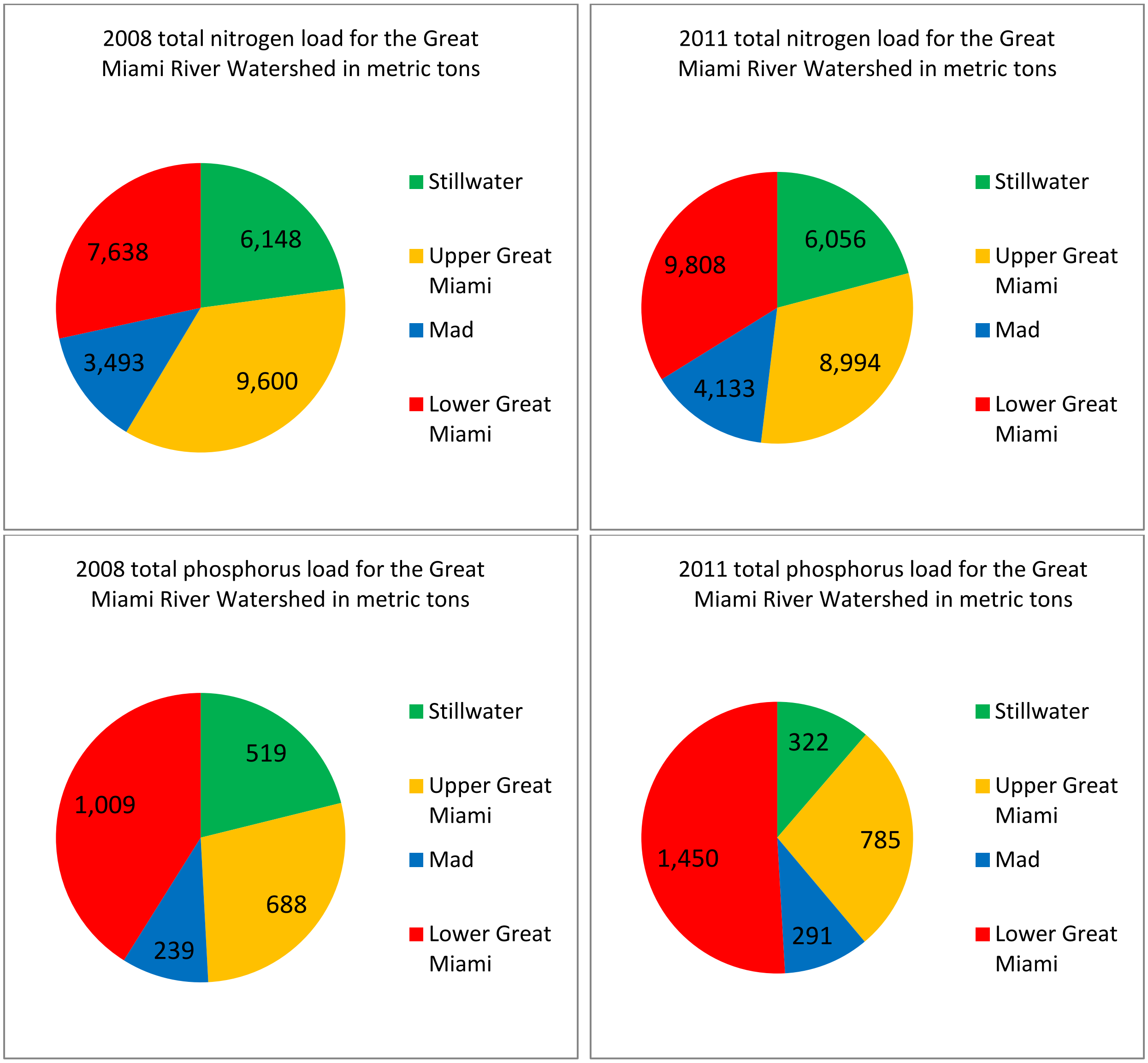
As part of this report, total nitrogen and total phosphorus loads for calendar years 2008 and 2011 were estimated for the Lower Great Miami River subwatershed. The data illustrate that higher nutrient loads and annual river discharge occurred in 2011 when compared with 2008.

Discussion of Annual Nutrient Loads

Overall, there is a high degree of correlation between annual discharge and nutrient loads. High discharge years tend to result in high annual loads and low discharge years tend to result in low annual loads. The Great Miami River near Fairfield station serves as an integrator station for the entire Great Miami River Watershed upstream of that station. Therefore, estimates of nutrient loads measured at the Great Miami River near Fairfield station can be used to estimate nitrogen and phosphorus export from the Great Miami River Watershed into the Ohio River Watershed.

Because all stations were operational in the years 2008 and 2011, comparisons can be made between the subwatersheds for these years (see Figure 10). Nutrient load calculations illustrate that the Upper Great Miami River subwatershed had the highest total nitrogen load in 2008 while the Lower Great Miami River subwatershed had the highest total nitrogen load in 2011. The Lower Great Miami River subwatershed had the highest total phosphorus loads in both years. In 2011, the Lower Great Miami subwatershed contributed slightly more than half of the total phosphorus load for the entire Great Miami River Watershed. The Mad River subwatershed had the lowest total nitrogen and phosphorus loads in both years.

Figure 10.Contributions of subwatersheds to total nitrogen and total phosphorus loads in the Great Miami River Watershed for the years 2008 and 2011.



Findings - Annual Nutrient Yields

The size of a watershed can overshadow the effects that land use and the physiography have on loads because large watersheds contribute large loads due in large part to their high volume of runoff (Reutter, 2003). The impacts of land use and physiography on nutrient loads in a given watershed are better observed when yields rather than loads are compared. The yield of a given watershed is calculated by dividing the pollutant load by the watershed area. Total nitrogen and total phosphorus yields are calculated in kilograms per square kilometer for all stations (see Table 7).

The highest annual total nitrogen yields were reported for the Stillwater River subwatershed when compared with the other subwatersheds. The annual total nitrogen yields measured for the Stillwater River subwatershed range from 2,030 to 3,652 kg/km^2 during 2006–2011. This is consistent with a study by Reutter (2003) of nitrogen and phosphorus in the Great Miami River Watershed.

Table 7. Annual nutrient yields for the Great Miami River Watershed and subwatersheds.

Constituent	Stillwater River at Englewood (Stillwater River Subwatershed)					
	2006	2007	2008	2009	2010	2011
Total Discharge (acre-feet)	614,696	663,828	754,258	377,304	474,368	862,054
Total Nitrogen (kg/km^2)	3,297	2,652	3,652	2,030	2,758	3,597
Total Phosphorus (kg/km^2)	98	217	308	70	104	191
Constituent	**Great Miami River at Huber Heights (Upper Great Miami River Subwatershed)**					
	2006	2007	2008	2009	2010	2011
Total Discharge (acre-feet)	N/A	N/A	1,478,988	528,798	669,138	1,773,883
Total Nitrogen (kg/km^2)	N/A	N/A	3,226	1,315	1,490	3,022
Total Phosphorus (kg/km^2)	N/A	N/A	231	58	105	264
Constituent	**Mad River near Dayton (Mad River Subwatershed)**					
	2006	2007	2008	2009	2010	2011
Total Discharge (acre-feet)	N/A	697,275	742,710	N/A	N/A	981,612
Total Nitrogen (kg/km^2)	N/A	1,971	2,124	N/A	N/A	2,513
Total Phosphorus (kg/km^2)	N/A	125	146	N/A	N/A	177
Constituent	**(Lower Great Miami River Subwatershed)**					
	2006	2007	2008	2009	2010	2011
Total Discharge (acre-feet)	N/A	N/A	1,164,511	N/A	N/A	2,291,745
Total Nitrogen (kg/km^2)	N/A	N/A	2,463	N/A	N/A	3,162
Total Phosphorus (kg/km^2)	N/A	N/A	325	N/A	N/A	468
Constituent	**Great Miami River near Fairfield (Great Miami River Watershed)**					
	2006	2007	2008	2009	2010	2011
Total Discharge (acre-feet)	N/A	3,471,558	4,141,823	N/A	N/A	5,911,167
Total Nitrogen (kg/km^2)	N/A	1,980	2,859	N/A	N/A	3,084
Total Phosphorus (kg/km^2)	N/A	161	261	N/A	N/A	303

The Mad River subwatershed had the lowest total nitrogen yields in 2007, 2008, and 2011. Total nitrogen yields for the Mad River subwatershed range from 1,971 to 2,513 kg/km^2 and illustrate less variability than the other subwatersheds and the entire Great Miami River Watershed.

The highest total phosphorus annual yield in 2008 and 2011 was reported from the Lower Great Miami River subwatershed when yields for all four subwatersheds could be calculated. The Mad River subwatershed had the lowest annual yields for total phosphorus in 2007, 2008, and 2011. Annual total phosphorus yields for the Stillwater River subwatershed illustrate considerable variability ranging from 70 to 308 kg/km^2. In 2008, the Stillwater River subwatershed had the second highest yield out of the four subwatersheds and in 2011; the Stillwater River subwatershed had the third highest yield.

Discussion of Nutrient Yields

The Stillwater River subwatershed consistently had the highest total nitrogen yield. The Mad River subwatershed consistently had the lowest total nitrogen yield.

Annual total phosphorus yields for the Great Miami River Watershed range from 161 to 303 kg/km^2. Estimates of annual total phosphorus yield are also somewhat higher than those of Goolsby et al., (1999) who estimated average annual total phosphorus yield at 123.3 kg/km^2 for 1980–1996. The differences in estimated total phosphorus yields between the two studies are probably due to the same factors contributing to the differences in total nitrogen yields. Once again a longer period of data collection is needed to better define mean annual phosphorus yields for the Great Miami River Watershed and all of its major subwatersheds.

The Lower Great Miami River subwatershed had the highest total phosphorus yield in both of the years (2008 and 2011) for which all the monitoring stations were operational. The Mad River subwatershed consistently had the lowest total phosphorus yield of the subwatersheds.

The total nitrogen and total phosphorus yields support the conclusion that the Great Miami River Watershed has some of the highest nutrient yields in the Mississippi-Atchafalaya River Basin (Goolsby et al., 1999).

Estimates of annual total nitrogen yield for the Great Miami River Watershed are somewhat higher than those of a study by Goolsby et al., (1999) who estimated an average annual total nitrogen yield at 1,480 kg/km^2 for the time period of 1980–1996. The differences may be due to the different methodologies used in the studies. Goolsby et al., (1999) derived their estimates for total nitrogen yield using multiple regression models as opposed to numeric integration of sample data. The model input data was based upon a much smaller number of samples (91 versus 1,730) used to represent a longer period of time (16 versus 3 years) than this investigation. Weather conditions may also have factored into the differences in estimated nitrogen yield. Two of the three years (2008 and 2011) for which total nitrogen data were collected at the Great Miami River near Fairfield station had above normal precipitation and river flows, which tends to favor higher nitrogen yields. A longer period of data collection is needed to better define mean annual nitrogen yields for the Great Miami River Watershed and all of its major subwatersheds.

Conclusion

In summary, the results of this study illustrate that Nitrate was the dominant species of total nitrogen and DIN comprising an average of 67 percent of the total nitrogen and 94 percent of the mean DIN concentration. Nitrate, DIN, and TKN concentrations tend to increase with increasing flow in all subwatersheds except the Mad River where nitrate and DIN concentrations actually decrease at high flows. Overall, nitrate, DIN, and TKN concentrations tend to be runoff-driven which suggests that nonpoint sources of nitrogen are of prime importance in determining nitrogen concentrations in the water column and total nitrogen export from the Great Miami River Watershed into the Ohio River Watershed.

The results of this study also illustrate that dissolved orthophosphate was the dominant form of phosphorus comprising an average of 63 percent of the mean total phosphorus concentration. Total phosphorus concentrations tend to increase at higher flows but also increase at lower flows suggesting that runoff driven and low flow driven sources of phosphorus are important in determining total phosphorus concentrations in the water column. However, runoff driven sources of phosphorus probably exert a greater control on total phosphorus export from the Great Miami River Watershed into the Ohio River Watershed due to the higher flows associated with runoff driven processes of phosphorus transport and greater overall flux. Dissolved orthophosphate concentrations at all monitoring stations tend to increase at lower flows but only the Stillwater River at Englewood monitoring station reported an increase in dissolved orthophosphate with increasing flow.

The calculations of nutrient loads and yields illustrate that the Upper Great Miami and Lower Great Miami River subwatersheds are the dominant contributors of total nitrogen load exported by the Great Miami River Watershed in 2008 and 2011. The results of this study show that the Lower Great Miami River subwatershed contributes the greatest fraction of the total phosphorus load exported by the Great Miami River Watershed in those same years. The Stillwater River subwatershed consistently had the highest total nitrogen yield from 2005–2011 The Lower Great Miami River subwatershed had the highest total phosphorus yield during 2008 and 2011. Total nitrogen and total phosphorus yields calculated for the Great Miami River Watershed in 2007, 2008, and 2011 exceeded published mean nutrient yields for the years 1980–1996.

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